University of Saskatchewan
Department of Physics and Engineering Physics
Physics 128.3 – Contemporary Physics
Final Examination

Time : 3 hours — Apr 17th, 2004

Circle your Instructor's Name :

D. Degenstein — A. Robinson

Student's Name: (Print) ______________________________________

Student Number: ______________________

Note : One 8.5 × 11 inch formula sheet is allowed.
Please answer the questions in the spaces provided.
Please show enough work to convince the marker you understand the material.
The back of each sheet may be used but please indicate that you have done so.
An extra blank sheet has been included in places where it may be required.
All questions are **NOT** allocated the same marks.
The assigned mark for each partial question is in parentheses near the answer space.

Good Luck!

1)	/ 18	2)	/ 15
3)	/ 14	4)	/ 14
5)	/ 13	6)	/ 15
7)	/ 14	8)	/ 12
9)	/ 15		
TOTAL:	/ 130		

Name: ______________________________

1) Two rocket ships are involved in a straight line space race. It is well known that one rocket ship is faster than the other so it is forced to go further. In order to keep things fair Joe and Beth are designated as the race officials. Joe is at the start line, Beth is at the finish line and they are separated by a proper distance of ***7 light minutes***. Both rocket ships are allowed to reach their maximum speeds as measured by the race officials, ***0.8c*** and ***0.9c*** for the slow and fast ship respectively, and then at time ***t = 0*** when all clocks involved in the race are synchronized Joe sees the slow ship cross the start line while the faster ship is ***1 light minute*** behind. Express your answers for distances in light minutes and times in minutes.
(All parts are worth two marks)

Answer parts a), b) and c) for time t = 0, the start of the race

a) How far does the pilot of the slower ship think it is to the finish line? ______________________

b) How far ahead is the slower ship as measured by the pilot of the faster ship? ______________________

c) What is the speed of the faster ship as measured by the slower ship? ______________________

d) According to Joe what time does the faster ship cross the start line? ______________________

e) According to its pilot what time does the faster ship cross the start line? ______________________

f) According to Beth what time does the slower ship cross the finish line? ______________________

g) According to its pilot at what time does the slower ship cross the finish line? ______________________

h) According to its pilot at what time does the faster ship cross the finish line? ______________________

i) How much time does the pilot of the fast ship think he loses by? ______________________

Name: ______________________________

2) Two circular water waves are continuously generated at two different points on a pond. A coordinate system is placed on the pond and in this coordinate system one source (source 1) is at the origin ***x = y = 0 m*** and the other source (source 2) is located at ***x = 2 m*** and ***y = 4 m***. Assume that the displacement of the water is identical for each of the sources and is given by

$$y(r,t) = 0.5\sin(10\pi\, r - 30\pi\, t)\,\mathbf{cm}$$

where ***r*** is the distance from the source in metres and ***t*** is the time in seconds.

a) How fast are each of the wave fronts propagating? ______________________ ***(1 mark)***

b) What is the period of each wave? ________________________ ***(1 mark)***

c) What is the wavelength of each wave? ____________________ ***(1 mark)***

Answer parts *d), e)* and *f)* for position *x = y = 1m.*

d) How much does source 1 displace the water at time ***t = 0.3 s***? ________________________***(2 marks)***

e) What is the total displacement of the water at time ***t = 0.8 s***? _________________________***(2 marks)***

f) What is the first time after ***t = 0 s*** when the water is not displaced? ____________________***(4 marks)***

g) Where is the first node, as measured from source 1, along the line that connects the two sources?

____________________________ ***(4 marks)***

3) Assume a mass spring system where the mass is ***1 kg*** and the spring constant is ***100 N/m***. This is not a normal classical system where the total energy can take on any value. It is a quantized system where the total energy, the sum of the kinetic and the potential energy, can only take on certain values given by

$$\boldsymbol{E}_{tot} = \boldsymbol{E}_0\left(\boldsymbol{n}+\frac{1}{2}\right)$$

where ***n*** is any positive integer including ***0*** and $\boldsymbol{E}_0 = 5\times10^{-5}\boldsymbol{J}$.

a) What is the angular frequency in ***rad/s*** that this system will oscillate at if it has a total energy given by ***n = 7***? __________________________***(2 marks)***

b) In the ***n = 6*** state what is the period of this system? _________________________***(2 marks)***

c) What is the minimum allowed kinetic energy that this system can have at its stable equilibrium point?_________________________***(2 marks)***

d) What is the difference in amplitude between the ***n = 20*** and ***n = 4*** states? _____________ ***(2 marks)***

e) If the system gives off a single photon as it goes from a higher to lower energy state what is the wavelength (in ***nm***) of the photon emitted as the system goes from the ***n = 2*** state to the ***n = 1*** state? ____________________***(2 marks)***

f) Assume the system is in its ***n = 4*** state. If we start measuring the position of the mass at a time ***t = 0 s*** when it is momentarily at rest what is the kinetic energy ***0.1 s*** later? __________________***(4 marks)***

Name: ________________________________

4) An alpha decay experiment given by the reaction

$$^{226}_{88}\boldsymbol{Ra} \rightarrow ^{222}_{86}\boldsymbol{Rn} + ^{4}_{2}\boldsymbol{He}$$

is conducted by a group of very long lived scientists onboard a spacecraft that speeds by the Earth at ***0.98c***. Assume, as viewed by an observer on Earth, that the alpha particles we are interested in are moving in the same direction as the spacecraft and the parent nuclei are stationary with respect to the spacecraft before they decay. Also, assume that the half-life of the reaction as measured by an experimenter on the spacecraft is ***1600 years*** and $M_{Ra} = 226.025403u$ $M_{Rn} = 222.017570u$ and $M_{He} = 4.002603u$ are the masses of the atoms. Recall $\mathbf{1u = 1.660539 \times 10^{-27}}$ ***kg*** and $\mathbf{1\ eV = 1.602 \times 10^{-19}\ J}$.

a) What is the half-life of the reaction as measured by an observer on Earth? _________________***(2 marks)***

b) If the experimenters on board the spacecraft start out with 1×10^{25} ***Ra*** nuclei at time ***t = 0 s*** what would they measure for the activity of their sample when an observer on Earth looked at his own watch ***12000 years*** later? ____________________________***(4 marks)***

c) How much energy do the parent nuclei have in the Earth reference frame? _________________ ***(2 marks)***

d) If the alpha particles gets 98.15% of the disintegration energy as kinetic energy how fast are they moving in the reference frame of the Earth? ________________________***(6 marks)***

Name: ______________________________

5) A ***1 gram*** sample of body tissue taken from the remains of an iron-age warrior found in a peat bog at Lindow Marsh near Manchester, England was measured to have a ^{14}C activity of ***0.168 Bq***. An independent measurement made by mass spectrometry reveals that the sample contains 4.39×10^{10} atoms of ^{14}C and 4.64×10^{22} atoms of ^{12}C. Recall that ***1 Bq = 1 disintegration/second*** and the ratio of ^{14}C to ^{12}C atoms in living tissue is 1.3×10^{-12}.

a) What is the decay constant for the radioactive decay of ^{14}C? _________________________***(2 marks)***

b) What is the half-life (in years) of the ^{14}C? ___________________________***(2 marks)***

c) What will the activity of the sample be one half-life from now? ______________________ ***(2 marks)***

d) What is the age (in years) of the remains of the warrior? ____________________________***(4 marks)***

e) If the instrumentation is such that the minimum activity that can be detected is ***0.03 Bq*** per gram of body tissue what is the maximum age of the warrior that can be determined using this method?
_________________________***(3 marks)***

Name: ________________________________

6) A laser sealed in a vacuum chamber produces a stream of photons with the frequency of $\boldsymbol{6.20x10^{14}}$ ***Hz***. The stream has a circular cross section with a diameter of ***2 mm***. Recall $h = 6.626\times10^{-34}\,J\cdot s$.

a) Calculate the wavelength of the photons.________________________***(2 marks)***

b) In what part of the electromagnetic spectrum do these photons appear?

__________________________***(1 marks)***

c) What is the energy of the photons, in electron volts? __________________________***(2 marks)***

d) What is the momentum of the photon in units of ***eV/c***?__________________***(2 marks)***

e) If the output power of the laser is ***1.05 W*** how many photons per second must it emit?

__________________________***(3 marks)***

f) What is the power per unit area (in $\boldsymbol{W/m^2}$) of the beam?________________________***(2 marks)***

g) The laser is now modified to fire $\boldsymbol{1.88x10^{18}}$ ***photons/second*** at a stationary target, which has a mass of $\boldsymbol{1.00x10^{-3}}$ ***kg***. The photon frequency remains the same. The laser is fired for ***10.0 seconds***. Assuming that the target absorbs all of the photons and that momentum is conserved, what is the speed of the target after ***10.0 seconds***? You may ignore any frictional effects.

__________________________***(3 marks)***

7) Photons with a wavelength of $\boldsymbol{3x10^{-10}}$ ***m*** are incident on a gold surface which has a work function of ***4.00 eV***. Recall the mass of an electron is $9.10939\times10^{-31}\,\boldsymbol{kg} = 5.48579\times10^{-4}\,\boldsymbol{u} = 0.510999\,\frac{\boldsymbol{MeV}}{\boldsymbol{c}^2}$.

a) What is the maximum kinetic energy of the photoelectrons? ____________________***(2 marks)***

b) Calculate the speed of the photoelectrons assuming that they receive half the maximum amount of kinetic energy? Ignore any relativistic effects. _________________________ ***(4 marks)***

c) Calculate the speed of the photoelectron assuming that they receive the maximum amount of kinetic energy? ***Do not*** ignore any relativistic effects. _________________________ ***(4 marks)***

d) Calculate the wavelength of the lowest energy photon that can remove an electron from the gold. __________________________ ***(2 marks)***

e) How much kinetic energy will the photo-electron given off in ***part d)*** have? ___________ ***(2 marks)***

8) A hydrogen atom in the $\boldsymbol{n = 7}$ orbital level emits a photon as it undergoes a transition to the $\boldsymbol{n = 2}$ state.

a) What is the wavelength of the photon in ***nm***? ________________________ ***(2 marks)***

b) What is the momentum of the photon in ***eV/c***? _______________________ ***(2 marks)***

c) What is the final Bohr radius for the orbit of the electron? ______________________ ***(2 marks)***

If the atom in the $\boldsymbol{n = 2}$ state absorbs a photon of wavelength ***200 nm*** and as a result the electron is now free:

d) What is the kinetic energy of the electron? __________________________ ***(2 marks)***

e) How much momentum does this electron have? ______________________ ***(2 marks)***

f) What is the relativistic correction factor γ for this electron? _________________________ ***(2 marks)***

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9) Three emission lines are seen to come from an atom and a set of very precise measurements indicate that the wavelengths of the photons are l_1***=434.1 nm***, l_2***=434.4 nm***, and l_3***=1085.25 nm***. For both measurement techniques described below assume that the light is normally incident upon the slits or grooves.

Assume the measurement technique involves two very small slits separated by a distance ***d = 20 mm*** and a viewing screen that is ***2 m*** away.

a) How high up the screen does the first bright maximum occur for the light of wavelength l_3?

___________________________***(2 marks)***

b) How far apart are the two ***m = -2*** bright fringes for the light with wavelengths l_1 and l_2?

___________________________***(2 marks)***

c) What is the lowest order ***m*** associated with the bright fringe for l_1 where there is also a bright fringe for l_3?___________________________***(2 marks)***

Now assume that the measurement technique involves a diffraction grating with uniformly spaced lines or grooves etched onto a aluminum substrate where the line density is 58000 lines/metre.

d) Calculate the angle of the third order bright fringe for l_3? ___________________________***(2 marks)***

e) What is the angular separation of the ***m = 2*** constructive interference maxima for the two wavelength separated by only ***0.3 nm***? ___________________________***(2 marks)***

f) Assume the optical system that is used with the grating is only capable of measuring the light that deviates by an angle that is less than ***0.2 radians*** from the normal to the diffraction grating. What is the largest angular separation that can be measured for interference maxima of the same order that involve the light of wavelengths l_1 and l_2? ___________________________***(5 marks)***